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Energy and carbon emission review for Macao's gaming industry

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A B S T R A C T

Energy consumption and CO_2 emissions caused by gaming industry have never been explored, while gaming industry across the world has experienced considerable development. To fill this blank, a comprehensive analysis based on systems accounting is conducted in this study for embodied energy consumption and CO_2 emissions by gaming industry, the backbone of Macao's economy. The results reveal that the total embodied energy consumption by Macao's pillar industry increases by about 1.5 times from 2005 to 2010 while the energy intensity decreases by more than a quarter. The trends of overall CO_2 emissions and emission intensity are in parallel to those of total energy consumption and energy intensity. It is also noted that as a service industry, indirect energy consumption and emissions induced by gaming is an order of magnitude larger than those based on direct accounting. As to the energy and emission structures, energy consumption and emissions caused by operating inputs is the largest contributor to both overall energy consumption and emissions. The results also indicate that for gaming industry's energy and emission issues, the relative importance of commission is increasing while that of goods purchased is decreasing. Appreciable energy saving and emissions reduction potential is also discussed against the background of Macao's urgent need for gaming industry's sustainable development.

Contents

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1. Introduction

In the context of energy crisis and climate change, our globe is confronted with serious challenges in balancing its social economic growth and human being's sustainable development [1]. The ever-increasing energy consumption and carbon emissions have stirred great concerns across the world in recent decades [2]. And to achieve sustainable development, governments at different scales are beginning to tackle with issues of energy consumption as well as anthropogenic carbon emissions from various economies [3–7]. Especially, energy consumption and related CO_2 released by important sectors of their economies are also investigated in recent years to provide information to understand the relationships between the economic development and their impact on environment [8–15]. Diverse approaches, such as input–output analysis and life cycle analysis, have also been applied as useful tools to measure some economic sectors' contribution to local regions' energy consumption as well as carbon emissions [16,17]. All the progress has provided important clues to help policy makers implement practical climate change mitigation measures.

The gaming industry is thriving worldwide as an international commercial activity. This industry usually refers to games of chance such as casino games, lotteries, machine gambling [18]. Nowadays, gaming has become an important industry in many parts of the world, as it can bring a large volume of revenues. At the global scale, total value of the legal gaming market was estimated as $335 billion in 2009 [18]. Take the USA as an example, gaming industry generated gross revenues of $92.27 billion in 2007 [18]. Meanwhile, gaming offers a large variety of job opportunities. Motivated by these significant benefits brought by gaming industry, more and more countries/regions gradually accept gaming and make it legal [19]. In the Asian Pacific Rim, casinos are thriving in Macao, Australia, Malaysia, Philippines, North and South Korea, Cambodia, Myanmar, Laos, Vietnam, and Russia [20]. In addition, some countries such as Singapore where gambling used to be entirely illegal have partially legitimized casinos. As a result, with more and more countries realizing the huge economic potential of gaming industry, gaming industry has been driven to develop at a rapid pace all over the world since the last century. In 1988 gaming was legalized in just 77 countries, this number steadily grew to 109 in 2001, according to Zou [21]. Moreover, initiatives to make gaming industry legalized are being discussed in countries/regions like Thailand, Taiwan and Japan [20]. There is no doubt that gaming industry is a major source of entertainment for millions of people, at the same time; it inevitably impacts the environment. In gaming industry, energy is utilized to heat, light and cool casino buildings, as well as for electric game machines and various appliances. Meanwhile, a lot of products such as food, beverages and machines are utilized to run gaming business every year. Usually these products are not produced locally; instead, they are imported from other regions. As a consequence, gaming industry induces certain amount of indirect energy requirements and CO_2 emissions. In addition, other economic sectors involved in gaming sector also consume a considerable amount of fuels and thus emit CO_2. For instance, transportation sector, which releases 6.62 billion tons of CO_2 in 2007 [22], has close relation to gaming industry. However, to our knowledge, among all the previous studies focusing on diverse economic sectors, there is still a lack of studies on CO_2 emissions caused by gaming industry across the world. Regarding the significant importance of energy and climate change issues, it is urgent to assess gaming industry's energy consumption and CO_2 emissions in the context of its sheer size.

Hence, we choose the world famous gaming industry in Macao to comprehensively investigate its energy consumption and CO_2 emissions in this study. Macao, as one of the two special administrative regions of China, is one of the most compact regions in the world. In 2010, the total land area of Macao is just 29.7 km^2 while the whole population is 544,600, i.e., 18,300 residents/km^2 [23]. After its sovereignty was handover to China, Macao has adopted aggressive gaming development strategy [20]. Since then the gaming industry began to experience tremendous success, making Macao the world's largest gaming hub in just five years [24]. Every year, millions of people rush to Macao to try their fortune or just for fun by gambling. To host so large number of tourists, gaming industry has to heavily depend on inputs of energy, commodities and services provided by other sectors, but all these inputs and sectors will consume energy and thus release CO_2 emissions. The flooding tourists attracted by gaming industry, on one hand, have brought enormous economic benefits to Macao, on the other hand, they make Macao's inherently fragile ecosystem much worse [25]. A scientific report points out that Macao has been badly influenced by world's climate change in the past as a coastal city [26]. Moreover, the growing energy demands of Macao puts great pressure on Macao's energy security as the majority of Macao's energy depends on imports from other regions [25]. Although the local government have realized the tough situation and expressed strong willingness to reduce energy consumption and CO_2 emissions, the lack of relevant research throws obstacle to tackle with the emission reduction issues. Figuring out the energy consumption and CO_2 emissions caused by gaming industry in Macao cannot only help local policy-makers to implement appropriate both energy conservation and emission reduction strategies, but also be adopted as reference to gaming industry's reduction actions in other parts of world, in light of the particular status of Macao's gaming industry in the whole world.

The structure of this paper is organized as follows: the second section overviews the historic development and the current state of gaming industry in Macao; methodology and data sources are presented in Section 3; in Section 4 the relevance between embodied energy consumption by main inputs of gaming industry is demonstrated; the results of CO_2 emissions caused by Macao's gaming industry is presented in Section 5; in Section 6 we discuss the feasible way to cut down the CO_2 emissions by gaming industry and CO_2 emissions reduction potentials based on the main results; finally, conclusion are made in Section 7.

2. Overview of gaming sector in Macao

The history of gaming in Macao can be stretched back to 16th century, when Macao first opened its harbor to foreign visitors from Europe [27]. When Macao was gradually replaced as an important trading port by Hong Kong, Macao's Portuguese government decided to choose gaming to alternate trading as the leading economic activity. In 1847, the government announced gaming

was legal for the first time, which established the bedrock of Macao's gaming sector's future booming. After this event, gaming sector became the main income source for Macao in late 19th century, with only a few decades' development. Since then, Macao was renowned as "Monte Carlo of the Orient". However, in a very long period, the right to run gaming business was monopolized by several big companies. Although the Portuguese Macao Government considered ending the monopoly system in gaming sector, there were no changes to gaming policy. On December 20th 1999, Macao seceded from the Portuguese and its sovereignty was handover to the People's Republic of China. Three years' after the foundation of Macao Special Administrative Region, the government took the historic step of abolishing the previous monopolized policy and opening up the rights to operate gaming sector. In 2002, 3 (later 6) concessionaires, namely, Sociedade de Jogos de Macao (SJM), Wynn Resorts, and Galaxy, won the bidding to have concessions. Attracted by the new policy, huge foreign investments flew into Macao. In May 2004, the first ever casino invested by American company in Asia was opened by Venetian, Casino Sands. According to statistics, the total number of casinos in Macao was 33, at the end of 2010.

With more than 400 years' development, nowadays the gaming activities become more diverse than they used to be. The gaming activities consist of various categories of casino games, horse racing, greyhound racing, sports betting and lotteries. The casinos, which provide many legal gaming forms called games of fortune such as blackjack, baccarat, roulette, boule, Sic bo, Fan Tan, keno and slot machines, are viewed the major parts of the whole gaming sector. As a result, casinos contributed the largest part of gaming revenues, followed by horse racing and sports lottery-football (Table 1). According to Gertina et al. [28], Macao was still the second largest gaming center after Las Vegas in 2003. Resulting from the government's reform on Macao's gaming development strategy, Macao was crowned as the world's biggest gaming center, surpassing Las Vegas the first time ever since 2007 [28].

Table 1
Gross revenue from different gaming activities in 2005–2010 (Unit: Million MOP).

Item	2005	2006	2007	2008	2009	2010
Games of fortune	46047	56623	83022	108772	119369	188343
Greyhound racing	67	67	98	186	327	340
Horse racing	636	437	403	501	333	439
Chinese lottery	7	7	6	6	6	6
Instant lottery	0.03	0.03	0.02	0.003	0.0024	0.0023
Sports lottery-football	333	327	273	304	52	380
Sports lottery-basketball	44	60	44	57	27	79

Source: Gaming inspection and coordination Bureau [27].

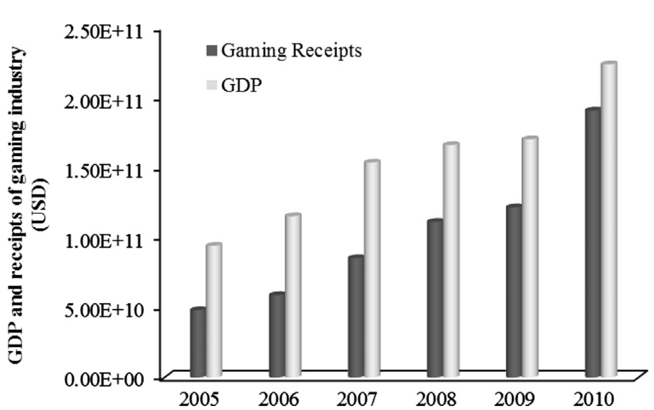


Fig. 1. The comparison of Macao's gaming receipts and GDP a *Source*: [a] [23, 31–35].

As the pillar of Macao's economy, gaming sector plays a major role in the lives and well-being of the local residents. While the gaming sector contributed about 30% of Macao's total income in 1990s, it has continued to be the main driving force of Macao's economy growth, especially after the termination of the monopoly in 2002 [29,30]. Shown in Fig. 1, the receipts of gaming sector amounted to 4.81E+10 US dollars in 2005 (the currency between Pataca and US dollar is 801.09 MOP to 100 USD), indicating that more than half of the same year's GDP came from gaming. In 2010, the receipts of gaming sector increased to 1.91E+11 US dollars, accounting for 85.22% of GDP. The economic growth and wealth that the industry has brought to the community has created numerous employment opportunities, and the Statistic and Census Services reports that unemployment has decreased from 6.4% in 2002 to 4.1% in the third quarter of 2005 with almost 58% of the population working in the industry [23,31–35].

3. Methodology and data sources

Gaming industry in Macao does not only need direct energy inputs in the form of fuels and electricity, but also requires indirect energy embodied in products and services. Meanwhile, gaming industry in Macao consumes large amount of materials and products imported from other regions or sectors and induces CO_2 emissions elsewhere. Thus, to draw a full picture of energy consumption caused by Macao, embodied energy as the sum of both direct and indirect energy should be taken into account. And to avoid carbon emissions leakage, embodied CO_2 emissions by gaming industry, including both direct and indirect emissions, should be evaluated. Chen and his colleagues have made significant contribution to constructing embodied energy intensity and carbon emission databases at different scales by applying systems accounting based on input–output analysis [3–6,36]. These databases cover detailed energy intensities of different economic sectors and carbon emission factors of various energy types, materials as well as economic sectors at global, national and regional scales, which provide solid foundation for Macao's gaming industry energy consumption and CO_2 emissions calculation in this study. Particularly, specific emission factors are adopted to suit the Macao situation.

3.1. Methodology

3.1.1. Energy consumption by gaming industry

The energy requirements of operating inputs (E) can be evaluated by

$$E=\sum_i E_{input,\,i}=\sum_i (EX_{input,\,i}\times EI_{input,\,i}) \tag{1}$$

where $E_{input,i}$ is the embodied energy consumption caused by input i, $EX_{input,i}$ is the expenditure (amount) of input category i and $EI_{input,i}$ is the energy intensity of input category i. Parameter i stands for various input categories, such as electricity, water, labor, commission, goods purchased, etc. The energy intensities of the Macao's gaming industry's inputs are listed in Table 2.

3.1.2. CO_2 emissions by gaming industry

Operating inputs

Here we divide operating inputs into two parts, energy inputs and other operating inputs. The CO_2 emissions from operating can be calculated as follows:

CO_2 emissions from energy inputs

Gaming industry in Macao has two types of energy inputs, one is electricity, which is also the major energy input; the other is fuel input. According to balance of energy 2005–2010, the electricity used by

Table 2
Energy intensities for inputs of Macao's gaming industry (Unit: J/10^4 CNY).
Source: [a] is derived from [3]. [b] is derived from [52], and the unit is J/10^4 kW h. [c] is calculated by authors based on [3].

Items	Energy intensity
Materials acquired	1.09E+10[a]
Water	3.60E+10[a]
Electricity	1.35E+11[b]
Diesel	1.12E+11[a]
Maintenance and repairs	2.37E+10[a]
Rent of establishment	5.23E+09[a]
Rent of machinery and equipment	2.22E+10[a]
Premiums on non-labor insurance	1.67E+10[a]
Bank charges	4.60E+09[a]
Communications	1.15E+10[a]
Marketing and publicity	2.27E+10[a]
Computer and information	2.70E+10[a]
Rent of vehicles	2.22E+10[a]
Uniform	2.49E+10[a]
Food and beverages	2.27E+10[a]
Hotel rooms, ferry and air tickets	3.18E+10[c]
Other contract services	2.27E+10[a]
Other operating expenses	2.27E+10[a]
Labor	1.18E+10[a]
Goods purchased	4.60E+09[a]
Commission	1.09E+10[a]

Table 4
GHG emission factors for inputs of Macao's gaming industry (Unit: t $CO_2/10^4$ CNY).
Source: [a] is derived from [3], [b] is derived from [44], and the unit is t CO_2/Tj. [c] is calculated by authors based on [4], and the unit is t $CO_2/10^4$ USD.

Items	Emission factors
Materials acquired	9.19E−01[a]
Water	3.12E+00[a]
Diesel	8.50E+01[b]
Maintenance and repairs	2.05E+00[a]
Rent of establishment	4.52E−01[a]
Rent of machinery and equipment	1.83E+00[a]
Premiums on non-labor insurance	1.41E+00[a]
Bank charges	3.90E−01[a]
Communications	9.98E−01[a]
Marketing and publicity	1.94E+00[a]
Computer and information	2.35E+00[a]
Rent of vehicles	1.83E+00[a]
Uniform	2.14E+00[a]
Food and beverages	2.28E+00[a]
Hotel rooms, ferry and air tickets	2.11E+00[a]
Other contract services	1.94E+00[a]
Other operating expenses	1.94E+00[a]
Labor	1.02E+00[a]
Goods purchased	2.63E+02[c]
Commission	3.90 E−01[a]

Table 3
GHG emission factors for electricity generation from 2005 to 2010 (Unit: t CO_2/Tj) [a].
Source: [a] is derived from [44]

Year	$EF_{imported}$	EF_{local}
2005	2.27E+02	1.69E+02
2006	2.23E+02	1.62E+02
2007	2.17E+02	1.58E+02
2008	2.28E+02	1.47E+02
2009	2.13E+02	1.50E+02
2010	2.08E+02	1.51E+02

Macao has two sources, one part is from local power plants, the other is imported from power plants in Mainland China [37–43]. Local power plants in Macao rely mainly on fuels combustion while power plants in Mainland China mainly use coal to generate electricity [37–43]. Thus, the emission factors of these two kinds of electricity differ from each other. However, we cannot tell how much electricity from each source is utilized by gaming industry. According to statistics, we get to know the exact proportions of electricity from each source in different years. As a result, we assume that electricity from each source has the same share as their total amount.

GHG emissions from electricity consumption can be calculated as follows

$$C_{electricity} = \sum_i (E_{electricity,\,i} \times EF_{electricity,\,i}) \tag{2}$$

where $C_{electricity}$ is the CO_2 emissions from electricity consumption; $E_{electricity,i}$ is electricity from source i (i.e., imported electricity, local electricity); $E_{electricity,i}$ is the emission factor of electricity from source i. The CO_2 emission intensities are adopted from Li and Chen [44], which are listed in Table 3.

According to Lei [45], the type of fuels consumed by gaming industry in Macao is diesel. The gaming companies offer free shuttle buses to tourists and carry them to travel between gaming places and transport connections. Thus certain amount of diesel is burned by shuttle buses. CO_2 emissions (C_{diesel}) attributable to fuel are determined by

$$C_{diesel} = M \times EF_{diesel} \tag{3}$$

where M stands for by diesel consumed by gaming industry, EF_{diesel} represents embodied emission factors for diesel. The CO_2 emission factor is also put in Table 4.

As a result, the CO_2 emissions of energy inputs (C_{energy}) can be obtained by combining CO_2 emissions from both electricity and diesel:

$$C_{energy} = C_{electricity} + C_{diesel} \tag{4}$$

Other operating inputs

The CO_2 emissions caused by other operating inputs can be obtained by multiplying the expenditure with the emission factor:

$$C_{input,\,j} = \sum_j (O_{input,\,j} \times EF_{input,\,j}) \tag{5}$$

where $C_{input,j}$ is the CO_2 emissions caused by input j, $O_{input,j}$ is the expenditure of input category j and $EF_{input,j}$ is the emission factor of input category j. Parameter j stands for various input categories with direct energy inputs excluded, such as water, financial services, etc. The emission factors of the other operating inputs are summarized in Table 4.The CO_2 emissions by other input (labor, goods purchased and commission) can be calculated by its emission factors and corresponding expenditure, with the value of emission factor presented in Table 4.

3.2. Data sources

This study used data from 2005 to 2010, a period of time in which Macao's gaming industry expands rapidly. Unless otherwise illustrated, the data on various kinds of inputs to gaming industry, which are classified as operating inputs, labor, goods purchased and commission, are provided by the Statistics and Census Service [46–51] and the Gaming Inspection and Coordination Bureau of Macao [27]. And data on energy intensities and CO_2 emission factors are derived from the aforementioned databases, which will be specified in Table 2–4.

Table 5
The embodied energy consumption by operating inputs (Unit: J).

Operating inputs	2005	2006	2007	2008	2009	2010
Materials acquired	2.88E+14	3.34E+14	5.33E+14	5.63E+14	5.74E+14	6.55E+14
Water	3.01E+13	3.73E+13	4.16E+13	4.36E+13	4.31E+13	4.26E+13
Electricity	3.38E+15	3.55E+15	7.79E+15	7.92E+15	1.41E+16	1.75E+16
Diesel	0.00E+00	0.00E+00	9.36E+12	4.91E+13	2.20E+13	2.46E+13
Maintenance and repairs	2.33E+14	3.27E+14	3.18E+14	3.66E+14	3.84E+14	4.49E+14
Rent of establishment	2.23E+13	3.23E+13	4.11E+13	4.36E+13	5.43E+13	3.98E+14
Rent of machinery and equipment	4.94E+14	4.52E+14	3.86E+14	4.71E+14	3.69E+14	1.43E+14
Premiums on non-labor insurance	4.60E+13	4.51E+13	7.32E+13	1.02E+14	8.37E+13	7.91E+13
Bank charges	1.81E+13	2.19E+13	7.09E+13	5.24E+13	3.96E+13	4.48E+13
Communications	7.12E+13	7.54E+13	8.45E+13	8.79E+13	8.28E+13	7.73E+13
Marketing and publicity	2.98E+15	3.85E+15	4.40E+15	2.13E+15	2.49E+15	3.37E+15
Computer and information	6.74E+13	9.76E+13	1.52E+14	1.09E+14	1.08E+14	1.49E+14
Rent of vehicles	0.00E+00	0.00E+00	2.62E+13	4.20E+13	4.80E+13	4.00E+14
Uniform	8.86E+13	9.58E+13	1.34E+14	1.15E+14	1.01E+14	6.95E+13
Food and beverages	3.07E+15	3.29E+15	3.62E+15	3.48E+15	2.80E+15	3.30E+15
Hotel rooms, ferry and air tickets	3.03E+15	3.53E+15	4.84E+15	6.22E+15	6.91E+15	7.06E+15
Other contract services	4.61E+14	1.39E+15	2.25E+15	1.73E+15	1.44E+15	1.66E+15
Other operating expenses	1.66E+15	1.42E+15	2.15E+15	2.93E+15	2.79E+15	2.76E+15
Total	1.59E+16	1.86E+16	2.69E+16	2.65E+16	3.25E+16	3.81E+16

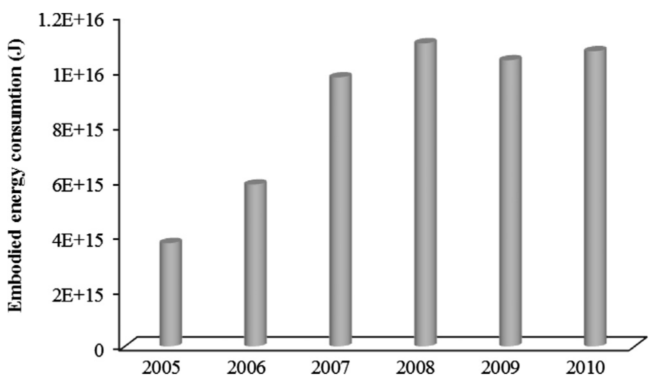


Fig. 2. Embodied energy consumption by labor.

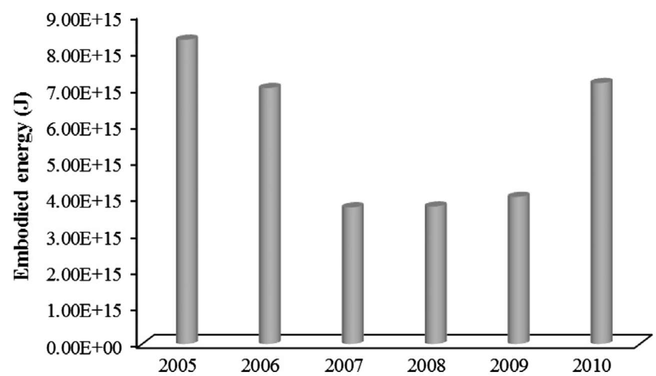


Fig. 3. Embodied energy consumption by goods purchased.

4. Energy consumption by Macao's gaming industry

4.1. Operating inputs

Table 5 gives the detailed result of the embodied energy consumption of operating inputs for Macao's gaming industry. From 2005 to 2010, the overall embodied energy consumption by gaming industry's inputs quickly grows from 1.59E+16 J in 2005 to 3.81E+16 J in 2010, i.e., the total amount increases by about 1.4 times in just five years' time. Among all the operating inputs, electricity is the largest individual contributor, followed by hotel rooms, ferry and air tickets, food and beverages and marketing and publicity. These four operating inputs are responsible for more than three-quarters of the overall energy embodied in overall operating input. On the contrary, the amount of energy embodied in Uniform, Bank Charges and Water on take a small fraction of the total operating input energy consumption.

4.2. Labor

As a service industry, gaming demands large number of workers to do jobs such as operating machines and offering services to customers. The fast-growing Macao gaming industry also creates great job opportunity for people in Macao. In 2010, the number of employers working for gaming sector is 44,806, accounting for 13.68% of the whole employed population [23]. In general, the workers of gaming sector in 2010 are almost twice as that in 2005 [46,51]. The expansion of labor consequently leads to the growth of embodied energy consumption, as portrayed in Fig. 2. In general, the embodied energy consumption caused by Macao's gaming industry's labor input increases from 3.74E+15 J in 2005 to 1.07E+16 J in 2010, with a growth rate of 64.97%. However, a small fluctuation appears in the accounting period, the embodied energy required by labor decreases in 2009 compared to that of 2008. That's because affected by world financial crisis in 2008, the gaming industry meet some economic trouble and cut down the number and cost of labor to ease this problem [46,49–51].

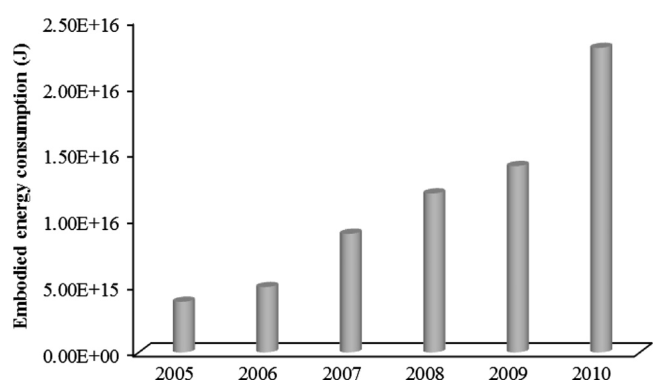


Fig. 4. Embodied energy consumption by commission.

4.3. Goods purchased

Presented in Fig. 3 is the embodied energy consumption by goods purchased from 2005 to 2010. First, the embodied energy sharply declines from 8.32E+15 J in 2005 to 3.73E+15 J in 2007, then starts to rebound and finally reaches 7.13E+15 J in 2010.

4.4. Commission

Unlike gaming industry in other parts of the world, Macao's gaming sector has a unique business model called VIP room, which is created to attract people called VIP customers who are willing to gamble with large amount of money. Traditionally, VIPs were defined as customers whose gambling budget is over 500,000 MOP, but nowadays, customers who are willing to spend no less than 100,000 MOP can also gamble in VIP rooms [53]. VIP rooms dominate Macao's gaming industry's revenue, with a proportion of more than 60% of the total [54]. However, the VIP rooms are heavily dependent on customer representatives who work as intermediate agent, i.e., customer representatives go out and find VIP customers and bring them to VIP rooms. Then customers can get money as their payment, which casinos called commission paid.

The termination of monopoly gives end to the exclusive rights to run gaming business and simultaneously leads to the fierce competition between different gaming companies. In 2004, the opening of one casino owned by Galaxy declares the war fighting for VIP customers begins the first time ever in Macao's gaming history. Since then, each gaming company tries their best to find more customer representatives to win more VIP customers. Against this background, the embodied energy consumption by commission has experienced significant growth in the period concerned. The amount of energy demanded by commission is 3.81E+15 J in 2005 and it soars to 2.29E+16 J in 2010, with a growth rate of over 500% (Fig. 4).

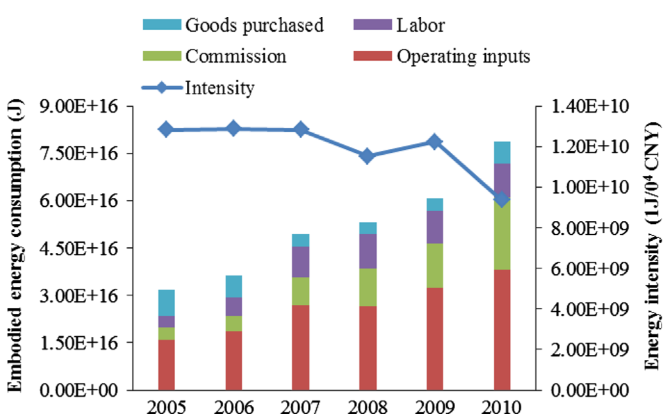


Fig. 5. Macao's gaming industry's total embodied energy consumption and its energy intensity.

4.5. Total energy consumption and intensity

The results show that the total embodied energy consumption caused by Macao's gaming industry is doubled after five straight years' growth. From 2005 to 2010, the embodied energy consumption by gaming industry goes up from 3.18E+16 J to 7.89E+16 J, while the direct energy input reported by the Gaming sector survey varies from 9.77E+14 J to 4.95E+15 J in the same period.

In terms of the energy consumption structure, operating inputs keeps its position as the biggest consumer from 2005 to 2010, while the smallest contributor has changed in the same period (Fig. 5). In the first two year, energy consumption by commission is smallest. However, with the commission booming, it becomes the second largest energy consumer and goods purchased replace it as the smallest one in 2010.

Fig. 5 also displays the energy intensity of Macao's gaming industry. The energy intensity of Macao's gaming industry ranges from 9.38E+09 J/10^4 CNY to 1.29E+10 J/10^4 CNY, and the energy intensity in 2006 is the highest while that of 2010 is the lowest. Unlike the trend of the total energy consumption, the energy intensity generally experiences decline in the period concerned because the overall revenue of gaming industry grows faster than its energy consumption. Compared to energy intensities of China's 135 economic sectors, the gaming industry of Macao ranks among the 10 lowest 10 energy intensive sectors, with an average value of 1.20E+10 J in the period concerned. This energy intensity is comparable to those of Manufacture of leather, fur, feather (down) and its products and Telecom and other information transmission services.

5. CO_2 emissions by Macao's gaming industry

5.1. CO_2 emissions by operating inputs

CO_2 emissions 2005–2010 caused operating inputs of Macao's gaming industry are summarized in Table 6. Although fluctuation

Table 6
CO_2 emissions from operating inputs (Unit: t)

Item	2005	2006	2007	2008	2009	2010
Materials acquired	2.43E+04	2.82E+04	4.49E+04	4.75E+04	4.84E+04	5.52E+04
Water	2.61E+03	3.23E+03	3.60E+03	3.78E+03	2.02E+04	3.70E+03
Electricity	1.73E+05	1.90E+05	4.22E+05	4.49E+05	7.54E+05	9.46E+05
Diesel	0	0	3.05E+02	1.41E+03	7.29E+02	7.41E+02
Maintenance and repairs	2.02E+04	2.83E+04	2.75E+04	3.16E+04	3.32E+04	3.89E+04
Rent of establishment	1.93E+03	2.79E+03	3.55E+03	3.77E+03	4.69E+03	3.44E+04
Rent of machinery and equipment	4.07E+04	3.73E+04	3.18E+04	3.88E+04	3.05E+04	1.18E+04
Premiums on non-labor insurance	3.88E+03	3.81E+03	6.18E+03	8.62E+03	7.07E+03	6.68E+03
Bank charges	1.53E+03	1.85E+03	6.01E+03	4.44E+03	3.36E+03	3.80E+03
Communications	6.18E+03	6.55E+03	7.33E+03	7.63E+03	7.18E+03	6.71E+03
Marketing and publicity	2.55E+05	3.29E+05	3.76E+05	1.82E+05	2.13E+05	2.88E+05
Computer and information	5.87E+03	8.50E+03	1.33E+04	9.45E+03	9.37E+03	1.29E+04
Rent of vehicles	0.00E+00	0.00E+00	2.16E+03	3.46E+03	3.96E+03	3.30E+04
Uniform	7.61E+03	8.24E+03	1.15E+04	9.86E+03	8.68E+03	5.98E+03
Food and beverages	3.08E+05	3.31E+05	3.63E+05	3.50E+05	2.82E+05	3.31E+05
Hotel rooms, Ferry and air tickets	2.67E+05	3.44E+05	3.97E+05	1.99E+05	2.29E+05	3.08E+05
Other contract services	3.94E+04	1.19E+05	1.92E+05	1.48E+05	1.23E+05	1.42E+05
Other operating expenses	1.42E+05	1.22E+05	1.84E+05	2.50E+05	2.39E+05	2.36E+05
Total	1.30E+06	1.56E+06	2.09E+06	1.75E+06	2.02E+06	2.46E+06

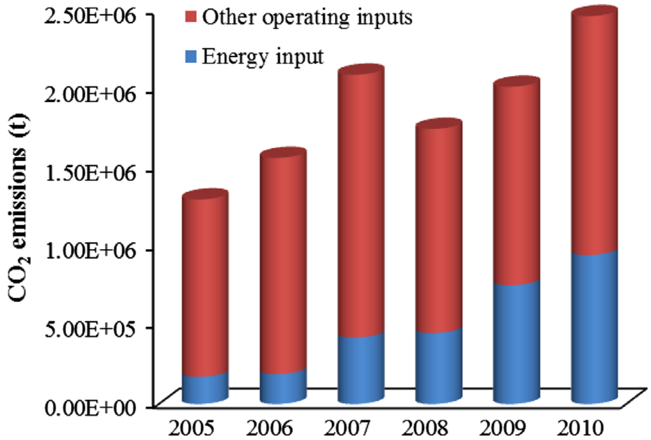


Fig. 6. CO_2 emissions caused by operating input.

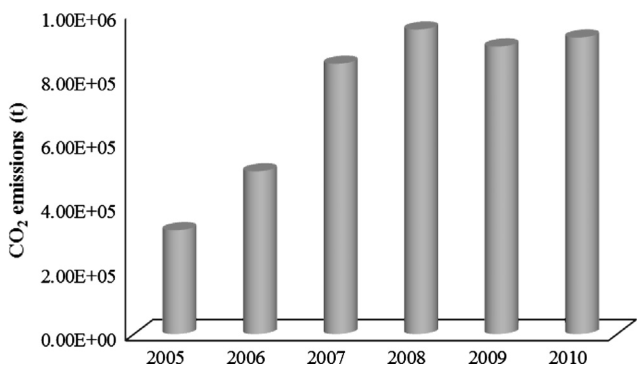


Fig. 7. CO_2 emissions from labor.

can be witnessed in the period concerned, generally CO_2 embodied in operating inputs experienced apparent growth.

As shown in Fig. 6, CO_2 emissions caused by gaming industry's energy consumption witness significant growth in the period accounted. In 2005, CO_2 emissions caused by electricity consumption are 1.73E+05 t. After five consecutive years' increase, the amount of CO_2 emissions increases about 4.5 times and gets to 9.46E+05 t. Electricity, which dominate the energy inputs, contributes the CO_2 emissions from energy consumption. That is because gaming industry cannot run without electricity. Electricity lights the casinos, supplies power to the air conditioning and ventilation systems, runs the gaming machines and sustains the operation of other electrical equipment. According to a report released by Washington State University [55], most of the gaming businesses, especially the casinos, stay open for 24 h, 7 days per week. Thus, gaming industry is considered to be a big electricity consumer and causing large amounts of CO_2 emissions. Unlike electricity, diesel only takes a very small share of the energy input. The CO_2 emissions caused by diesel consumption by buses dramatically fluctuate from 2007 to 2010, as presented in Table 6. First, the number of shuttle buses boom quickly after the introduction of the that new measure because of the fierce competition between different gaming companies, and the emissions significantly increase to 1.41E+03 t in 2008, which is about 4.6 times that of 2007. However, the shuttle bus is not that necessarily needed by visitors as gaming companies imagined and then they cut down the number of shuttle bus immediately [1]. Consequently, an obvious decline appears in the following two years, and the amount of CO_2 emissions in both 2009 and 2010 are just half of that in 2008.

Within other operating inputs, food and beverages and ferry and air tickets alternate the leading position as the largest emitter,

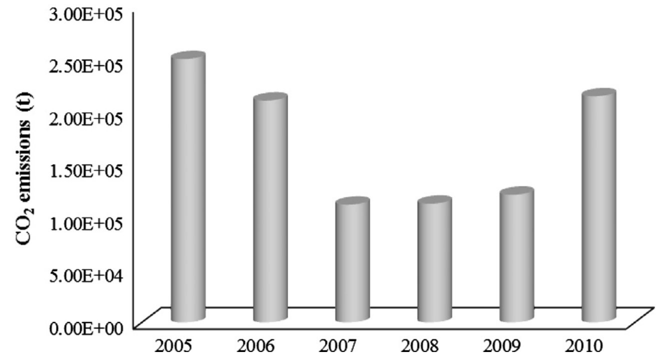


Fig. 8. CO_2 emissions from goods purchased.

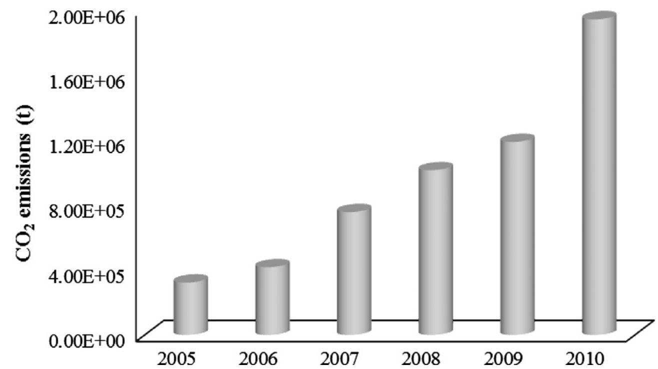


Fig. 9. CO_2 emissions from commission.

followed by marketing and publicity. Take food and beverages as an example, the amounts of CO_2 emissions from food and beverages range from 2.82E+05 t to 3.60E+05 t, accounting for 21.72–26.95% of the total. It is obvious that food and beverages, ferry and air tickets and marketing and publicity dominate the emissions of operating inputs, together contributing more than 60% of overall CO_2 emissions from 2005 to 2010. That's because gaming companies need to devote large amount of resources to marketing and publicity to attract customers, offer transportation services and provide food and beverages to visitors. In contrast to the three aforementioned inputs, Uniform, Bank Charges and Water contribute less than 1% of the total.

5.2. Labor

The trend of embodied CO_2 emissions induced by labor is similar to that of embodied energy consumed by labor. The uprising number of labor also leads to the growth of CO_2 emissions, as demonstrated in Fig. 7, CO_2 emissions are 3.24E+05 t in 2005, five years later, this amount reaches 9.24E+05 t. Emission decline also appears in 2009 and then a slight emission rebound can be seen in 2010.

5.3. Goods purchased

As depicted in Fig. 8, CO_2 emissions from goods purchased also experienced obvious fluctuation, CO_2 emissions in 2005 amount to 2.50E+05 t, then decrease to the lowest level with an amount of 1.12E+05 t. However, since 2007, CO_2 emissions of goods purchased begin to grow and finally reach 2.15E+05 t in 2010.

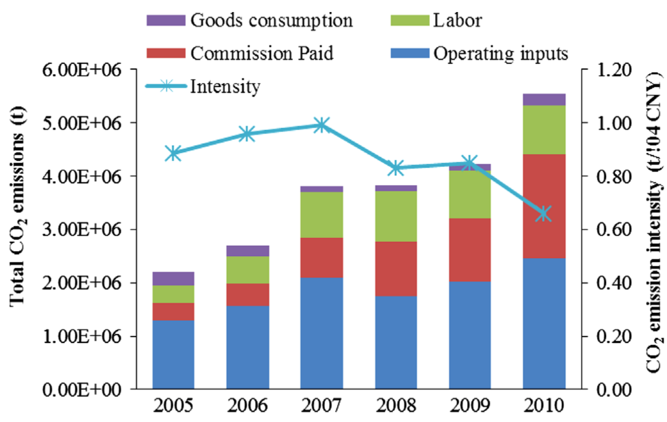


Fig. 10. Macao's gaming industry's total embodied CO_2 emission and its emission intensity.

5.4. Commission

Along with the energy consumption spike in accounting period, there has been substantial growth in CO_2 emissions caused by commission during the period of 2005–2010, as depicted in Fig. 9. The CO_2 emission in 2010 is 1.94E+06 t, which is about 6 times that of 2005.

5.5. Total CO_2 emissions and intensity

Fig. 10 presents the CO_2 emissions induced by Macao's gaming industry. During the period concerned, CO_2 emissions from gaming industry in Macao increased from 2.20E+06 t in 2005 to 5.55E+06 t in 2010, with a growth rate of 152.42%. In terms of CO_2 emission structure of gaming industry, operating inputs, including energy, contributes the largest share, while the goods consumption contribute the least. Additionally, the percentage of CO_2 emissions from commission keeps increasing from 2005 to 2010, while the share of goods consumption decreases. Although the proportion of total CO_2 emissions from labor fluctuates, it has apparent growth in general.

The trend of gaming industry's CO_2 emission intensity in Macao is totally different from that of overall CO_2 emissions. It is interesting to see that the emission intensity experience appreciable decrease in general (Fig. 10). The reason can be explained that the growth rate of CO_2 emissions is somewhat lower than that of gaming industry's income. Compared to CO_2 emission intensities of China's 135 economic sectors, CO_2 emission intensity of gaming industry in Macao is relatively low. Take the year of 2007 as an example, CO_2 emission intensity of gaming industry in Macao is 0.99 t/10^4 CNY. With comparison to those of 135 sector in China's economy, emission intensity of Macao's gaming industry stands among the 10 lowest emission-intensive sectors. And 0.99 t/10^4 CNY is a value which is comparable to those of China's Whole sale and retail sector, Telecommunication and other information transfer services sector.

6. Discussion

From the results we can see energy consumption and CO_2 emissions soar in period concerned along with the booming gaming industry resulted from Macao's aggressive development strategy. As the backbone of Macao's economy, the mitigation actions of gaming industry are necessary and vital to Macao's overall energy conservation and CO_2 emissions reduction. To implement appropriate measures, it is crucial to find out where the reduction potential lies and then develop feasible plans for realizing the targets. It is worth noticing that the both the energy consumption and CO_2 emission structures vary between 2005 and 2010, as shown in Figs. 11 and 12. The shares of CO_2 emissions and energy consumption by energy inputs and commission both have significant growth in the period time of 2005–2010, indicating that the relevant importance of energy consumption and CO_2 emissions from energy inputs and commission are substantially increasing. Here we can deeply discuss the potential energy saving and CO_2 reduction from these two parts.

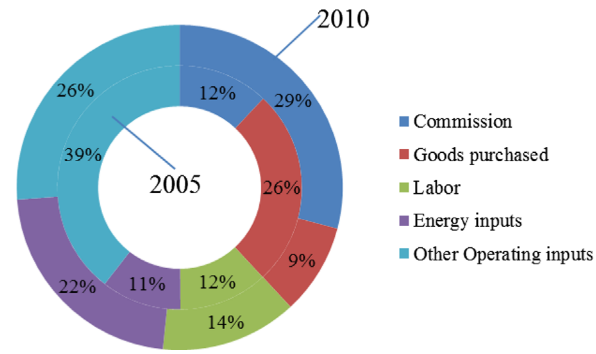


Fig. 11. Energy consumption structure of gaming industry in 2005 and 2010.

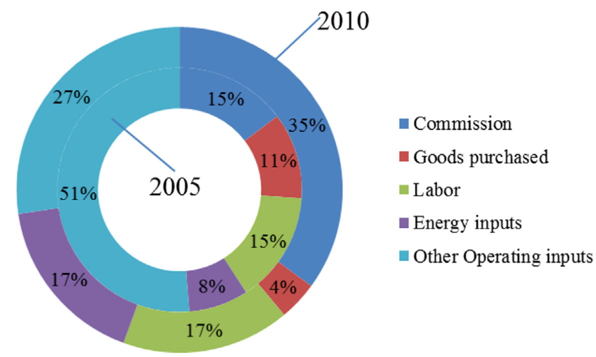


Fig. 12. CO_2 emission structure of gaming industry in 2005 and 2010.

6.1. Potential energy saving and CO_2 emissions reduction from commission

Among all the energy consumption and CO_2 emission categories of gaming industry, energy consumed and CO_2 released by commission have the fastest growing amount during the period concerned. The scale of Commission in 2010 is more than seven times that of 2005. The emission growth is led by the expansive scale of commission with uprising customer representatives, due to fierce competition for customers between gaming companies. Moreover, not only customer representative themselves lead to energy consumption and CO_2 emissions of commission; they need to go out the casinos by different kinds of transportation which burns fuels and thus emit CO_2.

On one hand, the expansion of energy consumption and CO_2 emissions by commission throws heavy burden on Macao's reduction efforts; on the other hand, it also means that there is great potential of both energy consumption and emission reduction in commission, for commission is not as necessary as other inputs to gaming industry, according to Wang [53]. On the contrary, the already existing commission system severely threatens the sustainable development of gaming industry nowadays. First, large part of revenues of gaming companies had to be paid to a large number of customer representatives, which remarkably increases the costs of gaming industry. Moreover, most of the customer representatives are non-Macao residents, no matter how much they get paid dose not made contribution to Macao's GDP. More importantly, disorderly competition of commission pushes Macao to be confronted with crisis [45]. It is fair to assert that cutting down commission cannot

just reduce its energy requirement and CO_2 emissions, but also create healthy environment for gaming industry's future development. Fortunately, both the government and stakeholders of gaming industry in Macao has noticed this serious problem and decide to regulate commission in the near future [53]. Actions like strictly control the number of customer representatives and get rid of many commission activities that are not necessary are suggested to be taken as soon as possible. It can be predicted that energy consumption and CO_2 emissions by commission will decrease with the decline of commission in the future.

6.2. Potential energy consumption and CO_2 emissions reduction from energy inputs

The results also show that both the absolute amount and the share of energy and CO_2 embodied in energy inputs by gaming industry have rapidly increased from 2005 to 2010. The embodied energy and CO_2 emissions spike by gaming industry's energy inputs can be attributed to two reasons, one is the expansion of gaming industry in Macao, and the other is that gaming industry, whose major energy source is electricity, is extremely energy-intensive. A previous study reports that per foot of casino buildings consumes more than five times as much energy as that of an average large modern hospital does [55]. And according to the statistics, gaming industry is responsible for more than 1/3 of Macao's overall electricity consumption [37–42,45]. Moreover, the electricity consumed by Macao is mainly imported from Mainland China, where the majority of power plants use high CO_2 emission-intensive coal to generate electricity. In addition, energy inputs will keep growing along the ever-increasing gaming industry in Macao, thus leads to more CO_2 emissions. There is no doubt that embodied energy consumption and CO_2 emissions caused by the booming gaming industry will be a more and more challenging problem to policy-makers.

Regarding its dominant position in Macao's economy, it is not practical to strictly control the scale of gaming industry. One feasible way to mitigate energy consumption and CO_2 emissions caused by gaming industry is to make gaming industry less energy-intensive. As a result, the policy makers and managers of gaming companies can think about reducing energy consumed and CO_2 emitted by per foot of casinos. A wide of ranges of measures can be carried to tackle with the energy and emission issue in gaming industry. For instance, green buildings which are less energy demanded by per square meter can be promoted by local governments and stakeholders, within the built environment. Energy inputs can be saved by incorporating energy-efficient technologies, such as compact fluorescent lamps, which give the same light as traditional incandescent lamps, but with one quarter of the energy [55]. Getting staff involved in can also be a good choice. The managers can set some programs aiming to increase staff awareness of energy management and teach them to identify ways to save energy through operational and maintenance improvements throughout the whole gaming industry.

7. Concluding remarks

Gaming industry is under fast development in more and more regions across our world, however, knowledge of its impacts on environment has been lacking. To fill this blank, this study presents embodied energy consumption and CO_2 emissions by gaming industry in Macao from 2005 to 2010. The following conclusions are drawn in this study.

The results show that overall embodied energy consumption in 2010 is almost 2.5 folds that in 2005, while the energy intensity decreases by about a quarter. Similarly, the total CO_2 emissions increase from 2.20E+06 t in 2005 to 5.55E+06 t, whereas emission intensity generally declines in the same period. In terms of energy consumption and emission structures, the operating inputs including is the largest contributor to gaming industry energy consumption and CO_2 emissions, while good purchased is the smallest at last. Also, commission and energy inputs are identified as the two fastest growing energy consumers and emission sources. It needs to be noted that the embodied energy consumption caused by gaming industry in Macao is an order of magnitude larger than the direct energy inputs reported by the statistics. It reflects the fact that as a service industry, gaming cannot run without inputs from other sectors. And a large amount of indirect energy consumption and CO_2 emissions from other sectors are induced by gaming industry. That's to say, from the systematic point of view, gaming industry should be responsible for both direct and indirect energy consumption and emissions other than those based on direct accounting.

In the context of global trend to mitigate climate change, Macao has expressed its concern on the environment and willingness to address energy conservation and CO_2 reduction. Since 2008, Kyoto Protocol was applied to Macao, which marks that Macao has become an official member which has obligation to reduce global CO_2 emissions. As a result, this presented work also commits to delivering insight for better formulating policies for Macao's gaming industry. For instance, appreciable energy savings and emission reduction will be realized if the following measures are taken: one practical way is to make gaming industry less energy-intensive by incorporating energy-efficient technologies; another is to strictly control the scale of commission. No doubt that making balance between ensuring continuous growth of gaming industry at an accelerating pace and reducing its impacts on environment is necessary for the sustainable development of Macao gaming industry.

As a matter of fact, besides the increasing energy consumption and CO_2 emissions, Macao's gaming industry is confronted with other challenges. More and more regions have started to open casinos in the world, thus gaming industry in Macao is facing more and more fierce competition. And in recent years, the gaming industry poses more serious income gap problem between the stakeholders and other local residents because of the inequality in the distribution of income, which causes the latter feel unsatisfied [24]. Fortunately, China's newly issued 12th Five-Year Plan has decided to support Macao to build itself into a world center of tourism and leisure center [56,57], which implies that Macao will receive strong support to sustain its gaming industry when it competes with other rivals. Moreover, the operators of gaming industry should cooperate closely with Macao government to formulate rational policies. Regulations should be issued to reduce blind expansion and disorder competition which may cause excessive resources consumption as well as heavy pressure on environment. To solve the income gap, it is worth noting that both the government and owners of gaming industry should bear in mind that the beneficiary group of Macao's gaming industry should cover as many as the local residents. Overall, to sustain Macao's industry's future development and attain the benefits in the uncertain environment, comprehensive strategies covering both environmental and social aspects are urgently needed.

Acknowledgements

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